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Combined Effect of Nano Silica and Steel Fiber on Compressive Strength and Water Permeability of Concrete

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ABSTRACT : *The Compressive strength and water permeability are experimentally evaluated on steel fiber (SF) reinforced concrete incorporated by nano silica (NS). NS is used as partial cement replacement by 1, 1.5, 2, and 4 wt%, and SF is used as volume substitution by 0.45, 0.9, and 1.35%. Scanning electron micrograph (SEM) is conducted for characterizing the concrete mixtures. Significant improvement in compressive strength of concrete by using both NS and SF, addition of NS can act as pozzolanic additive, and also as pore filling leading to reduce the pore size structure of concrete, hence increase in water permeability resistance by using NS is observed. Optimum content of NS is 2 wt% improves compressive strength for samples with 0% SF, 0.9% SF and 1.35% SF about 39%, 125% and 115% respectively compared to samples without either NS or SF. Optimum NS content of 4 wt% improved water permeability resistance compared to samples without NS.*

Keywords: *Nano silica; Steel fiber; Mechanical properties; Water permeability; Micro-structure*

I. INTRODUCTION

The permeability of concrete is an important property, it refers to the rate at which water or other aggressive substance (sulphates, chlorides ions, etc.) can penetrate concrete. It effects in the long-term durability of concrete [1]. Using nanoparticles can reduces the pore size structure of concrete by filling micro pore leading to increase in water permeability resistance. SiO_2 nanoparticles can improve the filler effect and its ultra high pozzolanic activity due to its amorphous structure causes more C–S–H gel formation [2]. Fresh concrete showed that the workability was reduced in the presence of SiO_2 nanoparticles. Hardened concrete showed that the optimal content of SiO_2 nanoparticles for improving concrete strength was set at 1.0 wt% [3]. Nano silica significantly increases the water demand in mortars and pastes as NS content increased due to particle size distribution and the high specific surface area of the material, as well as NS improve mechanical and physical properties of the concrete is observed [4, 5]. Sonication of NS helped increasing the concrete workability as a result of better dispersion of NS [6]. Using nano-particles incorporating polypropylene fibers improves frost resistance and compressive strength of concrete pavement as permeability and porosity of concrete are reduced due to the using nanoparticles [7]. Many studies focused on concrete durability, using nanoparticles can lead to decrease nano and micro pores so it can improve concrete durability. Frost resistance of concrete containing nanoparticles was improved, as microstructure found to be more compacted. Nano-Al_2O_3 was better than that containing the same amount of nano-SiO_2. Compressive strength of concrete containing nano-Al_2O_3 was lower than that containing the same amount of nano-SiO_2 [8]. The main objective of this research is to investigate the combined effect of using nano silica as cement substitution of concrete and steel fibers on concrete compressive strength and water permeability to perform concrete with the best characteristics.

II. EXPERIMENTAL PROGRAM

2.1. Materials

Ordinary Portland cement (OPC) is used as the main cementing material. It meets the requirements of ASTM C 150 [9]. The general chemical composition of the OPC is illustrated in Table 1. Nano SiO_2 (NS) with average particle size around (9 to 20) nm is used as received from physical laboratory at housing and building national research center (HBNRC). The utilized NS particles are expected to have high pozzolanic reactivity due to their amorphous structure. XRD test indicates the amorphous structure of NS as shown in Fig. 1.

Two types of aggregates are used in the concrete mix: fine aggregates and coarse aggregates. Fine aggregates used for the study are locally available natural sand. Fine aggregates pass the 4.75 mm (No. 4) sieve and retain on the 75 lm (No. 200) sieve [10]. Dolomite is used as coarse aggregates with particle size not exceed 14 mm. Super-plasticizer of polycarboxylate base (Glenium C315, BASF Co.) with 1.08 g/cm^3 specific gravity is used. Hooked end steel fibers (SF) made of low carbon steel wire with average length of 30 mm and average diameter of 0.8 mm is used. SF tensile strength is between 800 N/mm^2 to 1100 N/mm^2 and meeting the requirements of ASTM A820.

2.2. Mixture proportioning

A total of twenty mixes are performed in the laboratory. The control mixture is prepared without using NS or SF, other mixtures are prepared using NS as partial cement replacement by 1, 1.5, 2, and 4 wt%, and SF is used as volume substitution by 0.45, 0.9, and 1.35%. The mixes are divided into four groups and the mixtures proportions are illustrated in Table 2. Constant binder content of 450 kg/m^3 is used for all mixtures with 0.40 water to binder ratio (w/b) is set. The amount of SP is set at 0.8% of the binder (cement + NS) weight.

2.3. Mixing procedure and curing

Colloidal NS is applied for 10 minutes to ultra-sonication probe to be vibrated at very high speed to avoid agglomeration and to be more efficient in dispersing NS. In the performing of concrete, the dry materials are first mixed without fibers to avoid fiber balling for 1 min at low speed to obtain a homogenous mixture, then wet mixed at low speed for another minute, after that colloidal NS is added to prevent any agglomeration which may occurred and finally SF and SP are added and mixed at medium speed for 3 minutes, hence good workability concrete with uniform material is produced [11].

Samples were removed from the molds and kept in 22–25 ºC water until the suitable age for each experiment. Each mixing design includes six 150 mm cubic molds for compressive strength and three cylinders of 150 mm diameter and 300 mm height for permeability test.

2.4. Test methods

Compressive strength of concrete cubes is performed as per ASTM C 39 [12] after 7 and 28 days of moisture curing. Tests are carried out using a universal testing machine SHIMADZU 1000 kN on triplicate specimens and average compressive strength values are obtained. Permeability test was carried out on cylinders after 28 days of curing. Samples of 150mm height were dried applied to constant water pressure of 30 bars along 24 hours and were tightly sealed at top and bottom using rubber gaskets. SEM investigations are conducted on Quanta 250 FEG (Field Emission Gun). Backscattered electron (BSE) imaging is used to study the samples, which are equipped under situations that ensured their subsequent capability for analytical purposes.

III. RESULTS AND DISCUSSION

3.1. Compressive strength

The average test results of compressive strength of SF and NS are presented in Fig. 2 to Fig. 5. Nano silica produces huge amounts of high stiffness C-S-H condensed gel as a result of reaction with CH [13]. The compressive strengths of all concretes improved with the increase of NS and SF more than control mix.

The compressive strength of concrete is enhanced by 33% compared to the control mix using NS silica as cement substitution by 1.5wt% with 0.45% of SF. As well as, NS content value of 2 wt% optimum compressive strength is reached for sample with 0%, 0.9% and 1.35% SF.

In all mixes, when SF content increase to the value of 0.9% in the sample, optimum compressive strength is reached of the sample. Using 4 wt% NS reduces the compressive strength due to the agglomeration which reduce the amount of CSH.

3.2. Water permeability

The average test results of coefficient of water permeability of SiO_2 nanoparticles concretes are presented in Fig. 6 to Fig. 9. It is found that greatly improvement in water permeability resistance by adding NS through its high fineness that provides a filler effect. The results of permeability give good agreement with compressive strength results. Increasing permeability resistance of concrete is an important characteristic leading to improve durability.

Incorporating NS as cement substitution improves the permeability resistance about 63.5%, 93.3%, 94.5% and 355% by using 1 wt%, 1.5 wt%, 2 wt% and 4 wt% respectively for samples without SF.

Incorporating NS as cement substitution improves the permeability resistance about 7.1%, 41.7%, 46% and 115% by using 1 wt%, 1.5 wt%, 2 wt% and 4 wt% respectively for samples with 0.45% SF.

Using 1, 1.5, 2 and 4 wt% NS improved the permeability resistance about 28.1%, 28.1%, 67.9% and 178.3% respectively for samples with 0.9% SF. Using NS with 1, 1.5, 2 and 4 wt% improved the permeability resistance about 33.1%, 57%, 104.9% and 142.9% respectively for samples with 1.35% SF.

It is observed that the highest water permeability resistance results of all 20 mixes were reached using 4 wt% NS. The use of 4 wt% NS with 0.45, 0.9, 1.35% SF improve water permeability resistance by 185, 319 and 168% respectively compared to samples without either NS or SF.

Water permeability resistance decreases in the presence of steel fibers as it facilitate the bridging between pores. The fibers increased the water permeability coefficient due to the increase in flow rate as it act as a bridge between pores.

3.3. Scanning electron micrograph (SEM)

Uniformly dispersed nanoparticles in concrete makes the cement matrix more homogeneous and compact improving micro structure of concrete [14] as it fill the micro pores leading to reduction in porosity of concrete, the microstructure of the mixture containing NS revealed a dense, compact formation of hydration products, a reduced amount of CH crystals and reduction in formation of ettringite crystals are observed in Fig. 10 to Fig 12. The replacement of cement by 1.5 wt% and 2 wt% NS particles is found to enhance the hydration behavior and led to differences in the microstructure of the hardened pastes. The microstructure of the hardened cement paste containing NS appeared quite dense and compact with relatively less capillary pores as compared to the plain cement paste without NS. Concrete of 2 wt% NS gives less pores in microstructure of concrete than that of 1.5 wt%, hence the density of concrete increases as NS increased in concrete.

IV. FIGURES AND TABLES

4.1. Figures

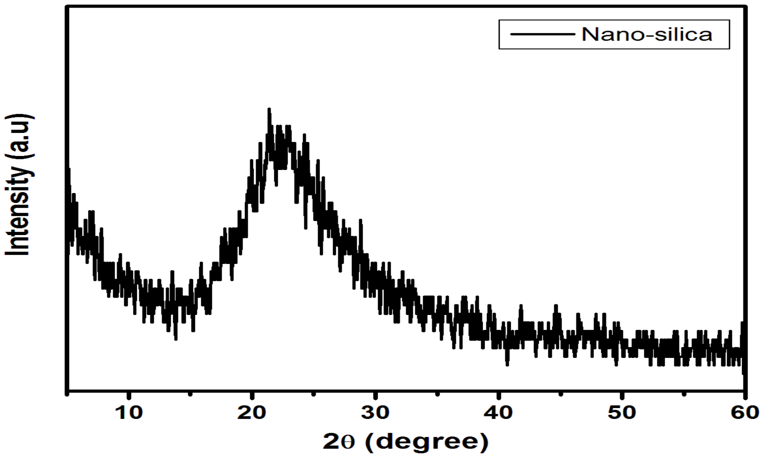

Fig. 1. XRD of SiO_2 nanoparticles with average particle size of (9-20) nm.

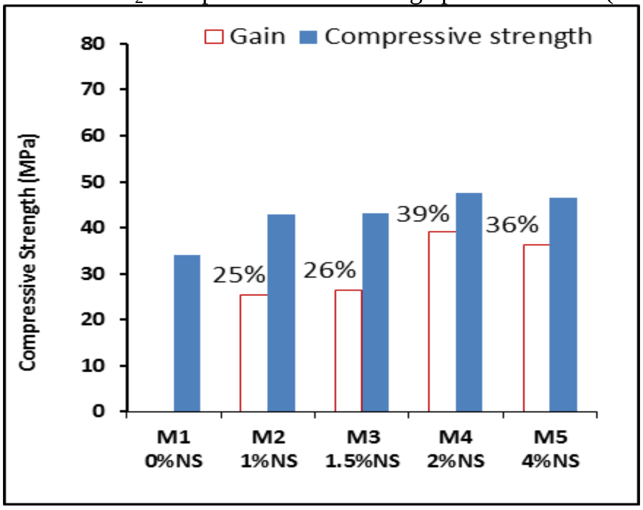

Fig. 2 Compressive strength and % gain for mixes with 0 % SF.

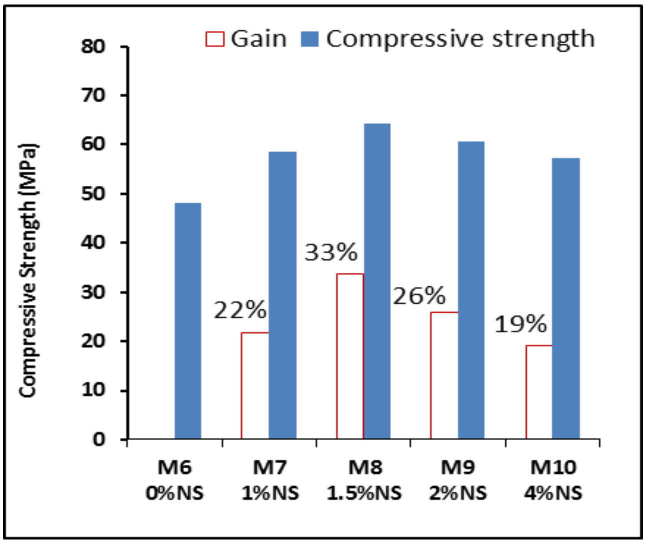

Fig. 3 Compressive strength and % gain for mixes with 0.45 % SF.

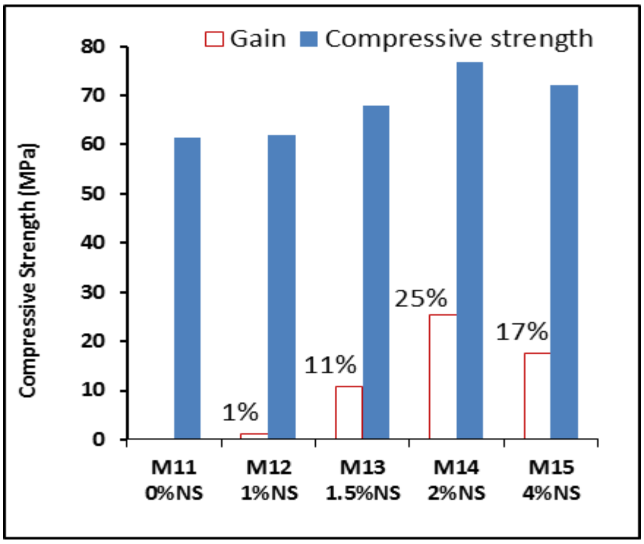

Fig. 4 Compressive strength and % gain for mixes with 0.9 % SF.

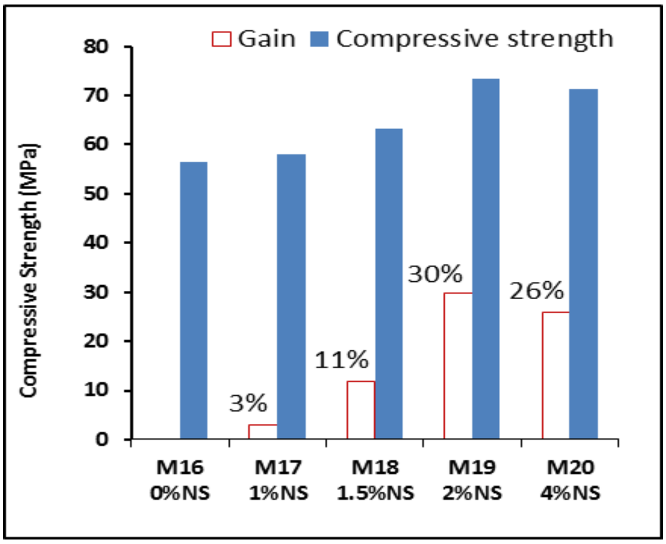

Fig. 5 Compressive strength and % gain for mixes with 1.35 % SF.

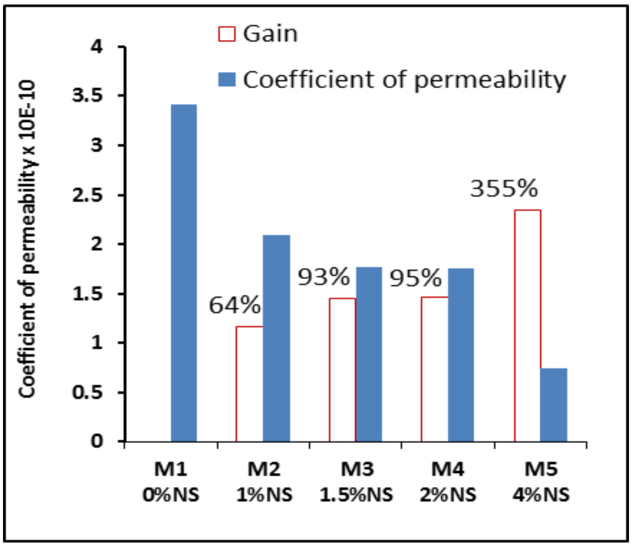

Fig. 6 Coefficient of permeability and % gain for mixes with 0 % SF.

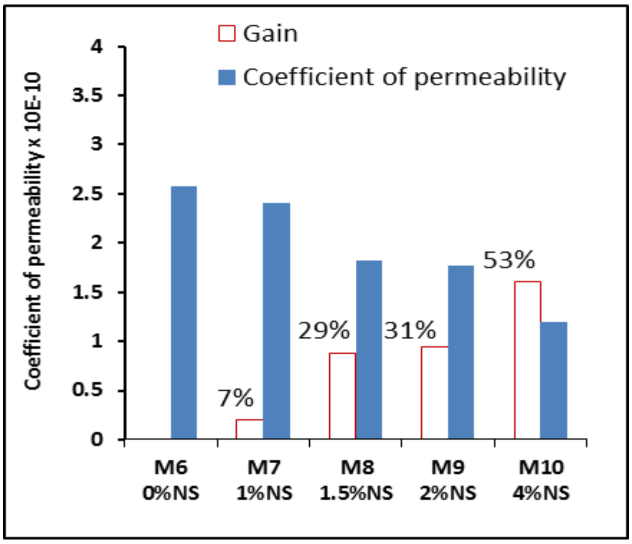

Fig. 7 Coefficient of permeability and % gain for mixes with 0.45 % SF.

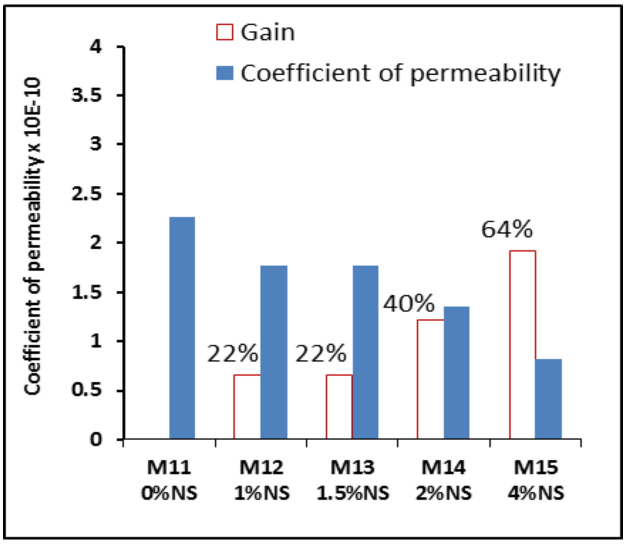

Fig. 8 Coefficient of permeability and % gain for mixes with 0.9 % SF.

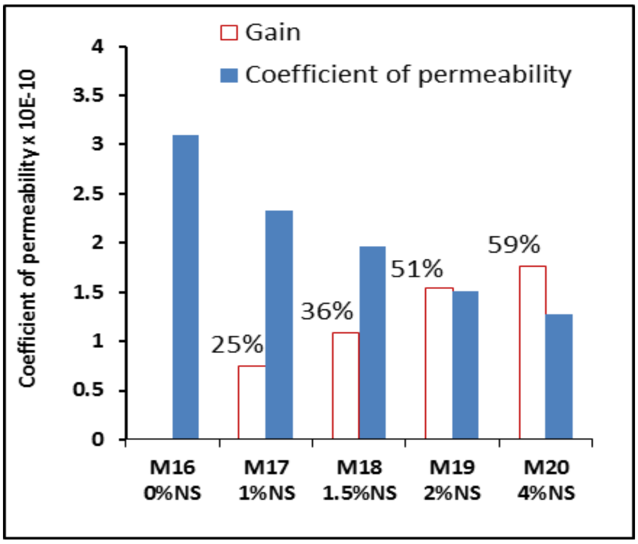

Fig. 9 Coefficient of permeability and % gain for mixes with 1.35 % SF.

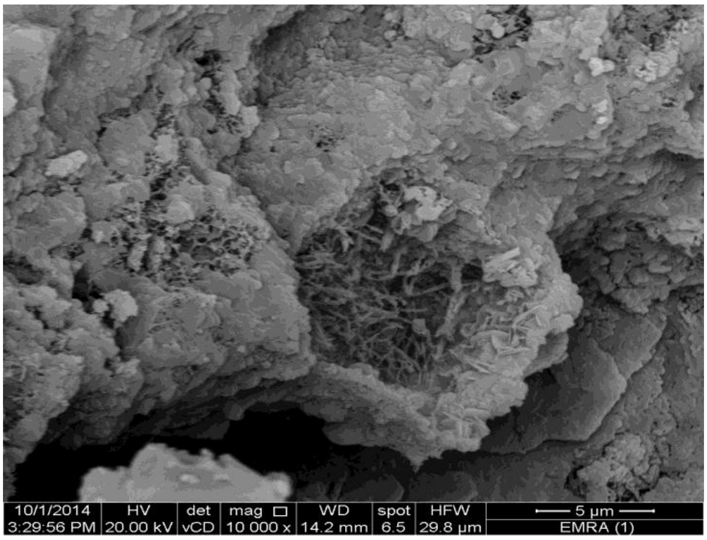

Fig. 10 Microstructure of M1 of 0 wt% NS and 0% SF at curing age of 28 days.

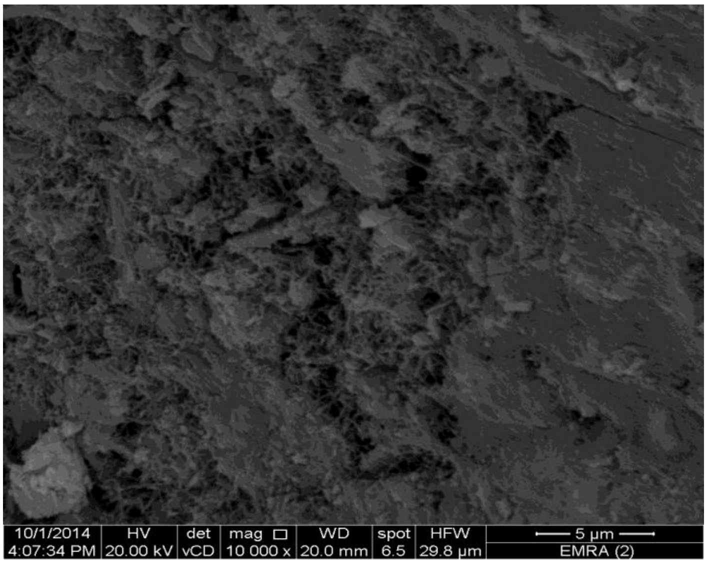

Fig. 11 Microstructure of M13 of 1.5 wt% NS and 0.9% SF at curing age of 28 days.

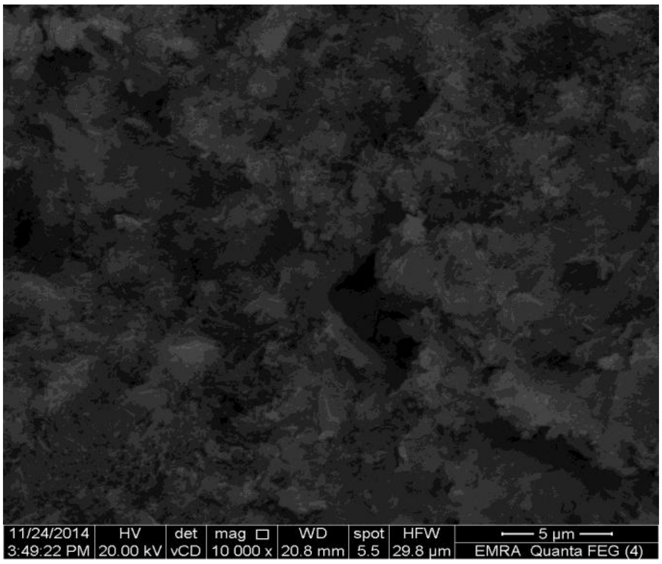

Fig. 12 Microstructure of M14 of 2 wt% NS and 0.9% SF at curing age of 28 days.

4.2. Tables

Table 1: Chemical composition of OPC (wt%).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I
Cement	21.03	4.09	3.03	61.45	1.74	3.50	0.48	0.37	4.08

Table 2: Mixture proportions of SF and NS blended concretes.

Group	Mix	SF (%)	NS (%)	Quantities (kg/m^3)		
				Cement	NS	SF
G1	M1	0	0	450	0	0
	M2		1	445.5	4.5	0
	M3		1.5	443.25	6.75	0
	M4		2	441	9	0
	M5		4	432	18	0
G2	M6	0.45	0	450	0	30
	M7		1	445.5	4.5	30
	M8		1.5	443.25	6.75	30
	M9		2	441	9	30
	M10		4	432	18	30
G3	M11	0.9	0	450	0	60
	M12		1	445.5	4.5	60
	M13		1.5	443.25	6.75	60
	M14		2	441	9	60
	M15		4	432	18	60
G4	M16	1.35	0	450	0	90
	M17		1	445.5	4.5	90
	M18		1.5	443.25	6.75	90
	M19		2	441	9	90
	M20		4	432	18	90

V. CONCLUSION

The following can be concluded from presented research:

1. Using NS as cement substitution leads to highly increase in compressive strength due to large amount of CSH formed by NS reaction with CH.
2. Mixes with more than 2 wt% NS decrease the compressive strength of concrete due to agglomeration of NS particles.
3. SF highly improves the compressive strength of concrete and the optimal level of SF content is achieved with 0.9% with all ratios of NS.
4. The optimum ratios of NS and SF are found to be 2 wt% and 0.9% respectively.

5. It is found that adding NS greatly increase water permeability resistance through its high fineness that provides a filler effect, hence improvement in the durability of concrete incorporated by nanoparticles.
6. The use of 4 wt% NS with 0.45, 0.9, 1.35% SF improve water permeability resistance by 185, 319, 168% respectively compared to samples without either NS or SF.
7. Utilizing 1, 1.5, 2 and 4 wt% NS improved the permeability resistance about 28.1%, 28.1%, 67.9% and 178.3% respectively for samples with 0.9% SF.
8. SEM shows that incorporating NS to concrete leads to more homogeneous and compact pastes by reducing the pore size structure of concrete filling micro cracks.

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